

- 1     What is claimed is:
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- 3     1.     A method of monitoring the capacity of a valve regulated lead acid battery, comprising:
- 4             connecting at least one battery monitor to said valve regulated lead acid battery;
- 5             connecting said monitor to a centralized system through an industry standard data system
- 6     that collects and transfers data from the field to a central office;
- 7             providing said centralized system with an alarm;
- 8             performing a short-term discharge test on said battery using said battery monitor; and
- 9             obtaining a predicted capacity using a neural network and fuzzy logic network in
- 10    combination with a prediction algorithm;
- 11             wherein, said discharge test provides input parameters for said networks which in
- 12    combination with said prediction algorithm calculate said predicted capacity, and wherein, said
- 13    alarm is activated when said predicted capacity falls below eighty percent, when an individual cell
- 14    voltage is reduced to 1.95 volts or less, or when a system failure occurs.
- 15     2.     A method as in claim 1, wherein said battery monitor consists of hardware for monitoring
- 16    the voltages of each battery cell and currents that are flowing into and out of said battery.
- 17     3.     A method as in claim 1, wherein said battery monitor contains a serial port enabling data to
- 18    be downloaded onto a network, computer, or printer.
- 19     4.     A method as in claim 3, further comprising a real time clock.
- 20     5.     A method as in claim 4, wherein said real time clock is automatically verified and updated
- 21    through said network.
- 22     6.     A method as in claim 1, wherein said discharge test is a four hour discharge test.

1    7.     A method as in claim 1, wherein said discharge test collects specific data parameters  
2     including the cell age, open circuit voltage, voltage after one hour of discharge, voltage after three  
3     hours of discharge, and voltage after four hours of discharge.

4    8.     A method as in claim 7, wherein said parameters are used to derive three additional data  
5     points including the slope of the discharge curve, the delta between voltages at three and four hours,  
6     and the proximity to two volts of the four hour voltage.

7    9.     A method as in claim 1, wherein said discharge test is performed on a repeated basis.

8    10.    A method as in claim 1, wherein said neural network is trained for a specific battery type in  
9     a lab by determining the actual capacity of a battery, inputting said parameters with the actual  
10    capacity used as a target, and programming the set of coefficients yielded by said neural network  
11    into an EEPROM which is inserted in said battery monitor.

12    11.    A method as in claim 10, wherein said actual capacity is determined by the following  
13    formula:

14                (time to discharge to 1.75V X 24 hour discharge rate)/(24 X 24-hour discharge rate in  
15                amps).

16    12.    A method as in claim 10, wherein said neural network is trained only once.

17    13.    A method as in claim 1, wherein said fuzzy logic network comprises:

18                dividing total battery capacity into capacity spans of ten percent;  
19                associating a voltage range with each of said ten percent spans, wherein said voltage range  
20                was previously determined from said 24-hour rate discharge lab tests;

21                determining within which of said capacity spans said voltage ranges fall by comparing each  
22                of said open, one, three, and four hour cell voltages with the known base lines for the specific  
23                battery type;

1 determining the strength value of the cell's voltage within a particular span;  
2 determining the capacity range with the most positive strength value;  
3 adjusting the range that is immediately above said capacity range with most positive strength  
4 value by adding the strength value of said range to the lowest capacity value of said range to yield  
5 the upper capacity limit;

6 adjusting the range that is immediately below said capacity range with most positive  
7 strength value by subtracting the strength value of said range from the highest capacity value of  
8 said range to yield the lower capacity limit;

9 wherein, said difference between said upper capacity limit and said lower capacity limit  
10 yields the fuzzy logic capacity range span.

11 14. A method as in claim 13, wherein said strength value is determined as follows:

12 calculating the average voltage for each capacity range using the maximum and minimum  
13 voltage values;

14 dividing the cell test voltage (open, one, three, or four hour) by said average voltage;  
15 subtracting the quotient of previous step from one and taking the absolute value of the  
16 difference;

17 performing this calculation for each of said cell test voltages--open ,one, three, and four  
18 hour;

19 adding the calculated values for each of said cell test voltages and dividing the sum by  
20 seventy; and

21 subtracting the quotient of the previous step from one;

22 wherein, the value of said strength value can be positive or negative.

23 15. The method of claim 1, wherein said neural network comprises:

1           inputting parameters including open, one-hour, three-hour, and four-hour cell voltages and  
2       the age of said battery;

3           obtaining three more data points from said parameters including slope of the discharge  
4       curve, the delta between voltages at three and four hours, and the proximity to two volts of the four  
5       hour voltage;

6           outputting a number between zero and one;

7           wherein, said neural network performs calculations as any standard neural network using the  
8       coefficients determined from said training of said network using lab data; and

9           wherein, the output of said neural network is multiplied by the span of the capacity range  
10      obtained from the fuzzy logic network and adding this product to said lower capacity limit in order  
11      to determine the final capacity prediction.

12     16. An apparatus for monitoring the capacity of a valve regulated lead acid battery, comprising:  
13       at least one battery monitor connected to said valve regulated lead acid battery;  
14       a centralized system connecting said battery monitor through an industry standard data  
15      system to a central office;  
16       an alarm connected to said centralized system;  
17       wherein, said battery monitor contains a neural network and a fuzzy logic network used in  
18      combination with a prediction algorithm; and  
19       wherein, said battery monitor contains a means for acquiring all data needed for said  
20      prediction algorithm.

21     17. An apparatus as in claim 16, wherein said battery monitor consists of hardware for  
22      monitoring the voltages of each battery cell and currents that are flowing into and out of said  
23      battery.

1       18. An apparatus as in claim 16, wherein said battery monitor contains a serial port enabling  
2 data to be downloaded onto a network, computer, or printer.

3       19. An apparatus as in claim 18, further comprising a real time clock.

4       20. An apparatus as in claim 19, wherein said real time clock is automatically verified and  
5 updated through said network.

6       21. A method of monitoring the capacity of a valve regulated lead acid battery, comprising:

7              connecting at least one battery monitor to said valve regulated lead acid battery;

8              connecting said monitor to a centralized system through an industry standard data system

9              that collects and transfers data from the field to a central office;

10             providing said centralized system with an alarm;

11             performing a short-term discharge test on said battery; and

12             obtaining a predicted capacity using a neural network and fuzzy logic network in

13             combination with a prediction algorithm;

14             wherein, said discharge test comprises a four hour discharge of said battery, performed at a

15             discharge rate calculated from the amp-hour size of the battery and a 24-hour period, during which

16             specific data parameters consisting of cell age, open circuit voltage, voltage after one hour of

17             discharge, voltage after three hours of discharge, and voltage after four hours of discharge are

18             logged and three additional parameters including three hour slope, the delta between the three and

19             four hour voltages, and the proximity to two volts of the four hour voltage are determined; and

20             wherein said neural network is trained in a lab by determining the actual capacity of a

21             battery using the following formula:

22              $(\text{time to discharge to } 1.75V \times 24 \text{ hour discharge rate}) / (24 \times 24\text{-hour discharge rate in})$

23             amps),

1           inputting said parameters with the actual capacity used as a target, and programming the set  
2        of coefficients yielded by said neural network into an EEPROM which is inserted in said battery  
3        monitor; and

4           wherein, said fuzzy logic network comprises dividing total battery capacity into capacity  
5        spans of ten percent; associating a voltage range with each of said ten percent spans, wherein said  
6        voltage range was previously determined from said 24-hour rate discharge lab tests; determining  
7        within which of said capacity spans said voltage ranges fall by comparing each of said open, one,  
8        three, and four hour cell voltages with the known base lines for the specific battery type;  
9        determining the strength value of the cell's voltage within a particular span by the following steps:

10          calculating the average voltage for each capacity range using the maximum and  
11        minimum voltage values; dividing the cell test voltage (open, one, three, or four  
12        hour) by said average voltage; subtracting the quotient of previous step from one and  
13        taking the absolute value of said answer; performing this calculation for each of cell  
14        test voltages (open one, three, and four hour); adding the calculated values for each  
15        of said cells test voltages and dividing the sum by seventy; and subtracting the  
16        quotient of the previous step from one;

17          determining the capacity range with the most positive strength value; adjusting the range that is  
18        immediately above said capacity range with most positive strength value by adding the strength  
19        value of said range to the lowest capacity value of said range to yield the upper capacity limit; and  
20        adjusting the range that is immediately below said capacity range with most positive strength value  
21        by subtracting the strength value of said range from the highest capacity value of said range to  
22        yield the lower capacity limit; wherein, said difference between said upper capacity limit and said  
23        lower capacity limit yields the fuzzy logic capacity range span; and

1 wherein, said neural network comprises inputting parameters including open, one-hour, three-hour,  
2 and four-hour cell voltages and the age of said battery; obtaining three more data points from said  
3 parameters including slope of the discharge curve, the delta between voltages at three and four  
4 hours, and the proximity to two volts of the four hour voltage; and outputting a number between  
5 zero and one; wherein, said neural network performs calculations as any standard neural net using  
6 the coefficients determined from said training of said network using lab data; and wherein, the  
7 output of said neural network is multiplied by the span of the capacity range obtained from the  
8 fuzzy logic network and adding this product to said lower capacity limit in order to determine the  
9 final capacity prediction.

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